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of

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for

SYSTEM AND METHOD FOR POLLUTANT REDUCTION IN A BOILER

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SYSTEM AND METHOD FOR POLLUTANT REDUCTION IN A BOILER

Related Applications

[0001] This patent application claims the benefit of, under Title 35, United States Code, Section 119(e), U.S. Provisional Patent Application No. 60/416,681, filed October 7, 2002.

Field of the Invention

[0002] This invention generally relates to a system and method for reducing pollution components from a combustion process and more specifically to a system for reducing such pollution components in a combustion boiler.

Background of the Invention

[0003] As is well-known, the combustion of fossil fuels (i.e., coal, natural gas, oil) in boilers, furnaces and the like leads to the creation of various pollution components. One of such pollution components is NOx (the various combinations of nitrogen and oxygen, primarily NO and NO_2), a pollutant that leads to smog and acid rain, especially in urban environments. Generally, the nitrogen for the formation of NOx comes from air that is introduced into the boiler for combustion, as air consists of approximately 21% oxygen and 79% nitrogen. Therefore, when oxygen is burned in a boiler, nitrogen is always present. At high temperatures the nitrogen will combine with the oxygen to form NOx. Moreover, as the

temperatures within the boiler increase, the formation of NOx also increases. At approximately 2200 °F NOx begins to form. As the temperature in the boiler increases beyond this temperature, the formation of NOx increases rapidly. At temperatures over approximately 2780 °F the formation of NOx generally doubles for each increase of about 190 °F. This is referred to as thermal NOx.

[0004] Systems and methods for reducing various pollution components produced during combustion processes, such as NOx, are known. One example of such a NOx control process is catalytic reduction in which the relatively cool combustion effluent of several hundred degrees Fahrenheit is passed over a catalyst coated bed in the presence of ammonia. This process is called selective catalytic reduction (SCR). However, while SCR is relatively effective at reducing NOx emissions (it can reduce NOx by more than 90% in some instances), it is a relatively complex process which is relatively expensive both to implement and operate.

[0005] Various other systems and methods for reducing NOx emissions have been developed which are far less complex and less costly than SCR. However, none of these known systems and methods have proven nearly as effective at reducing NOx emissions.

[0006] What is desired, therefore, is a system and method for reducing pollution components from a combustion process which is relatively highly effective at

reducing NOx emissions, which is relatively simple in design and operation as compared to other known processes which are of comparable effectiveness at reducing NOx emissions, which is relatively inexpensive both to implement and operate as compared to other known processes which are of comparable effectiveness, and which does not rely upon selective catalytic reduction (SCR).

Summary of the Invention

[0007] Accordingly, it is an object of the present invention to provide a system and method for reducing pollution components from a combustion process which is relatively highly effective at reducing NOx emissions.

[0008] Another object of the present invention is to provide a system and method for reducing pollution components from a combustion process having the above characteristics and which is relatively simple in design and operation as compared to other known processes which are of comparable effectiveness at reducing NOx emissions.

[0009] A further object of the present invention is to provide a system and method for reducing pollution components from a combustion process having the above characteristics and which is relatively inexpensive both to implement and operate as compared to other known processes which are of comparable effectiveness at reducing NOx emissions.

[0010] Still another object of the present invention is to provide a system and method for reducing pollution components from a combustion process having the above characteristics and which does not rely upon selective catalytic reduction (SCR).

[0011] These and other objects of the present invention are achieved by provision of a system and method for reducing pollution components from a combustion process. One embodiment of such a system in accordance with the present invention includes at least one burner modified in such a way so as to minimize production of at least one pollution component, an over fire air system which injects secondary air above the at least one burner, a tempering system which injects a cooling fluid into a combustion zone of the at least one burner so that the fluid is entrained to intersect an identifiable high pollutant component producing zone, a selective non-catalytic reduction system which injects a reagent into flue gases produced by the at least one burner, and a targeted chemical injection system which injects a pollutant component reducing agent into a nearby turbulent combustion zone of the at least one burner without a destruction of the agent by high temperatures, thus enabling the agent to be widely dispersed by the nearby turbulent zone before reaching a more distal zone where more favorable conditions for pollutant component reduction by the agent prevail.

[0012] In some embodiments, the pollutant component comprises NOx. In some embodiments, the at least one burner is modified by employing a technique selected

from the group consisting of a distribution analysis technique, a fuel balancing technique, a computational fluid dynamics combustion modeling technique, a flame stabilization technique, and combinations of these. In certain of these embodiments, the air distribution analysis technique comprises using actual data taken from burners in order balance secondary air between burners. In certain of these embodiments, the flame stabilization technique comprises a flame stabilizer which radially and circumferentially stages secondary air zone of burners to reduce pollutant component emissions.

[0013] In some embodiments, the over fire air system is adapted to inject air at a velocity selected so as to substantially complete combustion of uncombusted fuel. In some embodiments, about 70% to about 90% of combustion air comprises primary air mixed with fuel being combusted and about 10% to about 30% of combustion air comprises secondary air injected by the over fire air system. In certain embodiments, the cooling fluid injected by the tempering system comprises water, a gas or a mixture of water and gas. In some embodiments, the cooling fluid injected by the tempering system has a combined mass flow and temperature which is sufficiently low so that the cooling fluid reaches the pollutant component producing zone and cools it to a temperature where production of the pollutant component is reduced.

[0014] In some embodiments, the reagent injected by the selective non-catalytic reduction system is injected into an area where the flue gases have a temperature

in a range between about 1,500 °F and about 2,100 °F. In certain of these embodiments, the reagent injected by the selective non-catalytic reduction system is injected into an area where the flue gases have a temperature in a range between about 1,920 °F and about 2,100 °F. In some embodiments, the pollutant component reducing agent injected by the targeted chemical injection system is encapsulated within liquid or aqueous droplets that are so sized as to survive transit through the nearby turbulent combustion zone while evaporating by the time the agent reaches the more distal zone.

[0015] Another embodiment of the present invention concerns a system for reducing NOx from a combustion process which includes at least one burner modified by employing a technique selected from the group consisting of a distribution analysis technique, a fuel balancing technique, a computational fluid dynamics combustion modeling technique, a flame stabilization technique, and combinations of these, so as to minimize production of NOx, an over fire air system which injects secondary air above the at least one burner at a velocity selected so as to substantially complete combustion of uncombusted fuel, a tempering system which injects a cooling fluid into a combustion zone of the at least one burner so that the fluid is entrained to intersect an identifiable NOx producing zone, the cooling fluid having a combined mass flow and temperature which is sufficiently low so that the cooling fluid reaches the NOx producing zone and cools it to a temperature where production of NOx is reduced, a selective non-catalytic reduction system which injects a reagent into flue gases produced by the at least one burner in an

area where the flue gases have a temperature in a range between about 1,500 °F and about 2,100 °F, and a targeted chemical injection system which injects a NOx reducing agent into a nearby turbulent combustion zone of the at least one burner without a destruction of the agent by high temperatures, thus enabling the agent to be widely dispersed by the nearby turbulent zone before reaching a more distal zone where more favorable conditions for NOx reduction by the agent prevail.

[0016] In some embodiments, the air distribution analysis technique comprises using actual data taken from burners in order balance secondary air between burners. In some embodiments, the flame stabilization technique comprises a flame stabilizer which radially and circumferentially stages secondary air zone of burners to reduce NOx emissions. In certain embodiments, about 70% to about 90% of combustion air comprises primary air mixed with fuel being combusted and about 10% to about 30% of combustion air comprises secondary air injected by the over fire air system.

[0017] In some embodiments, the cooling fluid injected by the tempering system comprises water, a gas or a mixture of water and gas. In some embodiments, the reagent injected by the selective non-catalytic reduction system is injected into an area where the flue gases have a temperature in a range between about 1,920 °F and about 2,100 °F. In certain embodiments, the NOx reducing agent injected by the targeted chemical injection system is encapsulated within liquid or aqueous droplets that are so sized as to survive transit through the nearby turbulent

combustion zone while evaporating by the time the agent reaches the more distal zone.

[0018] A further embodiment of the present invention concerns a system for reducing NOx from a combustion process which includes at least one burner modified by employing a technique selected from the group consisting of a distribution analysis technique, a fuel balancing technique, a computational fluid dynamics combustion modeling technique, a flame stabilization technique, and combinations of these, so as to minimize production of NOx, an over fire air system which injects secondary air above the at least one burner at a velocity selected so as to substantially complete combustion of uncombusted fuel, and a tempering system which injects a cooling fluid into a combustion zone of the at least one burner so that the fluid is entrained to intersect an identifiable NOx producing zone, the cooling fluid having a combined mass flow and temperature which is sufficiently low so that the cooling fluid reaches the NOx producing zone and cools it to a temperature where production of NOx is reduced.

[0019] In certain embodiments, the air distribution analysis technique comprises using actual data taken from burners in order balance secondary air between burners. In certain embodiments, the flame stabilization technique comprises a flame stabilizer which radially and circumferentially stages secondary air zone of burners to reduce NOx emissions. In some embodiments, about 70% to about 90% of combustion air comprises primary air mixed with fuel being combusted and about

10% to about 30% of combustion air comprises secondary air injected by the over fire air system. In certain embodiments, the cooling fluid injected by the tempering system comprises water, a gas or a mixture of water and gas.

[0020] In another respect, the present invention is directed to a method for reducing pollution components from a combustion process. In one embodiment, such a method includes the steps of modifying at least one burner in such a way so as to minimize production of at least one pollution component, injecting secondary air above the at least one burner, injecting a cooling fluid into a combustion zone of the at least one burner so that the fluid is entrained to intersect an identifiable high pollutant component producing zone, injecting a reagent into flue gases produced by the at least one burner, and injecting a pollutant component reducing agent into a nearby turbulent combustion zone of the at least one burner without a destruction of the agent by high temperatures, thus enabling the agent to be widely dispersed by the nearby turbulent zone before reaching a more distal zone where more favorable conditions for pollutant component reduction by the agent prevail.

[0021] In some embodiments, the pollutant component comprises NOx. In some embodiments, the modifying step comprises the step of modifying at least one burner by employing a technique selected from the group consisting of a distribution analysis technique, a fuel balancing technique, a computational fluid dynamics combustion modeling technique, a flame stabilization technique, and combinations of these so as to minimize production of at least one pollution component. In certain

of these embodiments, the air distribution analysis technique comprises the step of using actual data taken from burners in order balance secondary air between burners. In certain of these embodiments, the flame stabilization technique comprises the step of radially and circumferentially staging a secondary air zone of burners to reduce pollutant component emissions.

[0022] In some embodiments, the injecting secondary air step comprises the step of injecting air at a velocity selected so as to substantially complete combustion of uncombusted fuel. In some embodiments, about 70% to about 90% of combustion air comprises primary air mixed with fuel being combusted and about 10% to about 30% of combustion air comprises secondary air injected above the at least one burner. In certain embodiments, the injecting a cooling fluid step comprises the step of injecting water, a gas or a mixture of water and gas. In some embodiments, the injecting a cooling fluid step comprises the step of injecting a cooling fluid having a combined mass flow and temperature which is sufficiently low so that the cooling fluid reaches the pollutant component producing zone and cools it to a temperature where production of the pollutant component is reduced.

[0023] In some embodiments, the injecting a reagent step comprises the step of injecting a reagent into an area where the flue gases have a temperature in a range between about 1,500 °F and about 2,100 °F. In certain of these embodiments, the injecting a reagent step comprises the step of injecting a reagent into an area where the flue gases have a temperature in a range between about 1,920 °F and about

2,100 °F. In some embodiments, the injecting a pollutant component reducing agent step comprises the step of encapsulating the pollutant component reducing agent within liquid or aqueous droplets that are so sized as to survive transit through the nearby turbulent combustion zone while evaporating by the time the agent reaches the more distal zone.

[0024] Another embodiment of the present invention concerns a method for reducing NOx from a combustion process which includes the steps of modifying at least one burner by employing a technique selected from the group consisting of a distribution analysis technique, a fuel balancing technique, a computational fluid dynamics combustion modeling technique, a flame stabilization technique, and combinations of these, so as to minimize production of NOx, injecting secondary air above the at least one burner at a velocity selected so as to substantially complete combustion of uncombusted fuel, injecting a cooling fluid into a combustion zone of the at least one burner so that the fluid is entrained to intersect an identifiable NOx producing zone, the cooling fluid having a combined mass flow and temperature which is sufficiently low so that the cooling fluid reaches the NOx producing zone and cools it to a temperature where production of NOx is reduced, injecting a reagent into flue gases produced by the at least one burner in an area where the flue gases have a temperature in a range between about 1,500 °F and about 2,100 °F, and injecting a NOx reducing agent into a nearby turbulent combustion zone of the at least one burner without a destruction of the agent by high temperatures, thus enabling the agent to be widely dispersed by the nearby turbulent zone before

reaching a more distal zone where more favorable conditions for NOx reduction by the agent prevail.

[0025] In some embodiments, the air distribution analysis technique comprises the step of using actual data taken from burners in order balance secondary air between burners. In some embodiments, the flame stabilization technique comprises the step of radially and circumferentially staging a secondary air zone of burners to reduce pollutant component emissions. In certain embodiments, about 70% to about 90% of combustion air comprises primary air mixed with fuel being combusted and about 10% to about 30% of combustion air comprises secondary air injected above the at least one burner. In some embodiments, the injecting a cooling fluid step comprises the step of injecting water, a gas or a mixture of water and gas.

[0026] In certain embodiments, the injecting a reagent step comprises the step of injecting a reagent into an area where the flue gases have a temperature in a range between about 1,920 °F and about 2,100 °F. In some embodiments, the injecting a pollutant component reducing agent step comprises the step of encapsulating the pollutant component reducing agent within liquid or aqueous droplets that are so sized as to survive transit through the nearby turbulent combustion zone while evaporating by the time the agent reaches the more distal zone.

[0027] A further embodiment of the present invention concerns a method for reducing NOx from a combustion process which includes the steps of modifying at least one burner by employing a technique selected from the group consisting of a distribution analysis technique, a fuel balancing technique, a computational fluid dynamics combustion modeling technique, a flame stabilization technique, and combinations of these, so as to minimize production of NOx, injecting secondary air above the at least one burner at a velocity selected so as to substantially complete combustion of uncombusted fuel, and injecting a cooling fluid into a combustion zone of the at least one burner so that the fluid is entrained to intersect an identifiable NOx producing zone, the cooling fluid having a combined mass flow and temperature which is sufficiently low so that the cooling fluid reaches the NOx producing zone and cools it to a temperature where production of NOx is reduced.

[0028] In some embodiments, the air distribution analysis technique comprises the step of using actual data taken from burners in order balance secondary air between burners. In some embodiments, the flame stabilization technique comprises the step of radially and circumferentially staging a secondary air zone of burners to reduce pollutant component emissions. In certain embodiments, about 70% to about 90% of combustion air comprises primary air mixed with fuel being combusted and about 10% to about 30% of combustion air comprises secondary air injected above the at least one burner. In some embodiments, the injecting a cooling fluid step comprises the step of injecting water, a gas or a mixture of water and gas.

[0029] The invention and its particular features and advantages will become more apparent from the following detailed description considered with reference to the accompanying drawings.

Brief Description of the Drawings

[0030] **Figure 1** is schematic view illustrating the various layers of a system and method for reducing pollution components from a combustion process in accordance with an embodiment of the present invention;

[0031] **Figure 2** is a graphical representation illustrating the results attainable using the system and method of Figure 1 and comparing the results thereof to those attainable using SCR;

[0032] **Figures 3A** and **3B** are schematic views illustrating operation of a flame stabilization aspect of a burner modification layer of the system and method of Figure 1;

[0033] **Figures 4A** through **4C** are schematic views further illustrating operation of the flame stabilization aspect shown in Figures 3A and 3B;

[0034] **Figure 5** is a schematic view illustrating operation of a over fire air layer of the system and method of Figure 1;

[0035] **Figure 6** is a schematic view illustrating operation of a NOx tempering layer of the system and method of Figure 1;

[0036] **Figure 7** is a schematic view illustrating operation of a selective non-catalytic reduction layer of the system and method of Figure 1; and

[0037] **Figure 8** is a schematic view illustrating operation of a targeted chemical injection layer of the system and method of Figure 1.

Detailed Description of an Embodiment of the Invention

[0038] As opposed to known NOx reducing techniques, the system and method of the present invention is based upon the concept of both minimizing NOx production within a boiler while at the same time neutralizing NOx which has been produced. Traditionally, NOx reduction techniques have focused only upon one or the other of these concepts.

[0039] Referring to Figure 1, the system 10 of the present invention is shown in general schematic terms. More specifically, the system 10 of the present invention relies upon a layered combination of NOx reducing techniques including burner

modifications 12, the introduction of overfire air (OFA) 14, NOx tempering 16, selective non-catalytic reduction (SNCR) 18 and targeted chemical injection of NOx reducing agents 20. Each of these techniques is described in more detail below.

[0040] Referring now to Figure 2, an example of the results attainable using the system 10 of the present invention is graphically illustrated and compared to the results attainable using SCR. In this example, suppose the baseline emissions of a boiler are 0.90 pounds of NOx per million Btu's released (lb/MMBtu). The burner modifications 12 employed by the present invention can reduce this amount of emissions to approximately 0.41 lb/MMBtu. The use of the contemplated overfire air (OFA) technique 14 can further reduce this amount of emissions to approximately 0.30 lb/MMBtu, and the use of the contemplated NOx tempering technique 16 can reduce the emissions to approximately 0.26 lb/MMBtu. The amount of NOx emissions can be reduced further to approximately 0.18 lb/MMBtu by employing the contemplated SNCR technique 18 and still further to approximately 0.09 lb/MMBtu by employing the contemplated targeted chemical injection of NOx reducing agents technique 20. As can be seen in the graph, the result of the layered technique employed by the present invention is comparable to the 0.09 lb/MMBtu which can be attained using SCR.

Burner Modifications

[0041] Various burner modifications 12 which may be employed by the present invention include airflow distribution analysis, fuel balancing, computational fluid

dynamics (CFD) combustion modeling and flame stabilization. As each of these methods is generally known in the prior art, only a brief overview is given herein, particularly where improvements over the prior art techniques are presented.

[0042] The air distribution analysis (ADA) employed by the present invention is used to balance secondary air between burners. The technique uses actual data taken from burners, rather than information inferred from downstream data or drawn from simulated conditions (as is the case with typical known ADA). Airflow balancing datasets are collected from inside the burner throat, at the critical fuel-air interface to create definitive diagnostic performance results. Typically, over 2,400 individual data readings are taken for each burner. As a result, this technique provides reliable, accurate results to ± 1.5%. Results identify airflow differences between burners, differences within the burner itself and the precise nature and location of any inefficient windbox air distribution for each unit.

[0043] Balancing the fuel flow from burner-to-burner coupled with airflow balancing (using ADA as described above) ensures that the minimum furnace excess oxygen level is achieved. Fuel balancing and reduced furnace excess oxygen are beneficial to unit heat rate, boiler thermal efficiency, superheater temperature profiles, flame stability as well as NOx reduction.

[0044] For purposes of illustration and not limitation, in coal firing a rotorprobe and dirty air pitot tube can be used to measure the existing burner primary air and coal

flow deviations. The rotorprobe is an effective measurement technique of coal flow distribution deviations and "roping' in the coal pipe runs, prior to the burner. This enables changes to be made to existing pipe orifices to correct the fuel distribution to ±10%. Alternatively, in order to limit outage time, balancing dampers for each coal pipe may be installed, which facilitates the on-line adjustment of the fuel balance. The balance of fuel and air is confirmed by measuring loss on ignition (LOI), $\%0_2$ and CO across a sampling grid at the boiler or economizer outlet flue. A coal distribution device may also be provided to eliminate the coal "roping" in the burner.

[0045] CFD combustion modeling may also be employed to verify the baseline burner NOx and CO emissions and to design the burner modifications. The final burner configuration, including the flame stabilizer (see below) is modeled to ensure complete burnout of the fuel with low CO and NOx emissions. The difference between the baseline and modified burner emissions determine the percent NOx reduction from the burner modifications.

[0046] A flame stabilizer 22, such as disclosed in U.S. Patent Nos. 5,131,334, 5,365,865 and/or 5,415,114, which are commonly owned with the present invention and which are hereby incorporated by reference in their entirety, may be added to each burner to stabilize the combustion process and allow the unit to be operated at lower excess O_2. In addition, the flame stabilizer 22 may radially and circumferentially stage the secondary air zone of the burners to reduce NOx

emissions. This design creates the minimum swirl necessary to maintain a stable fire. The remaining secondary air is injected in a low or non-swirl mode outside the primary combustion zone (see Figures 3A). The application of the flame stabilizer allows the air doors 24 to be set in a full open (see Figure 4A) or nearly full open position (see Figure 4B), removing any inconsistencies between burners which may result when the air doors being fully closed (see Figure 4C). The quantity of air is effectively controlled in the primary combustion zone where the majority of the NOx emissions are formed. To enhance the NOx reduction capabilities of the burner modifications, the flame stabilizer 22 is designed with internal air/fuel staging. This sets up fuel rich and lean zones downstream of the stabilizer 22 in the primary combustion zone (see Figure 3B). This provides additional staging, flame stability and, lower NOx emissions.

Overfire Air (OFA)

[0047] Referring now to Figure 5, NOx emissions can be further reduced through the use of overfire air (OFA) ports 26. An OFA system 14 can be supplied and installed to divert secondary air above the top row of burners 28. The ports are designed to inject air at the proper velocity to complete combustion prior to the furnace exit. Typically, OFA ports 26 and burners 28 are disposed within a windbox 30.

[0048] More specifically, OFA technology requires the introduction of combustion air to be separated into primary and secondary flow sections to achieve complete

burnout and to encourage the formation of N_2 rather than NOx. Primary air (70-90%) is mixed with the fuel producing a relatively low temperature, oxygen deficient, fuel-rich zone and therefore moderate amounts of fuel NOx are formed. The secondary (10-30%) of the combustion air is injected above the combustion zone through a special windbox with air introducing ports and/or nozzles, mounted above the burners. Combustion is completed at this increased flame volume. Hence, the relatively low-temperature secondary-stage limits the production of NOx, particularly thermal NOx.

NOx Tempering

[0049] Referring now to Figure 6, a NOx tempering system 16 is another layer that can be added to incrementally reduce NOx. Such a system, an example of which is disclosed in more detail in U.S. Patent No. 5,690,039, which is commonly owned with the present invention and which is hereby incorporated by reference in its entirety, involves spatially selectively injecting a cooling fluid into the combustion zone of a burner so that the fluid is entrained to intersect an identifiable high NOx producing zone. The cooling fluid can be water, a gas or a mixture of water and gas whose temperature is sufficiently low or whose combined mass flow and temperature are sufficiently low so that the cooling fluid can reach the NOx producing zone and cool it to a temperature where the NOx production is significantly reduced.

Selective Non-Catalytic Reduction (SNCR)

[0050] As discussed above, selective non-catalytic reduction (SNCR) 18 may also be employed by the present invention. In this process, an aqueous solution containing a reagent (typically urea-based with chemical enhancers) is injected into the flue gases. The reagent reacts chemically with the NOx in the combustion gas to form harmless nitrogen, water, and a small amount of CO. As shown in Figure 7, however, the reagent must be injected into the furnace flue gas in a location having an appropriate temperature window. The temperature window for SNCR operation typically occurs between 1,500°-2,100°F (815°-1,150°C), below which NH_3 (ammonia) is formed and above which NOx emission levels actually increase. The optimum temperature window for the most efficient SNCR operation typically occurs between 1,920°-2,100°F (1,050°-1,150°C). This appropriate temperature window typically occurs somewhere in the steam generator and connective heat-transfer areas. The longer the reagent is at optimum temperature, the higher the NOx reduction. As such, the reagent may be injected into the flue gases in the lean fuel zone above the furnace, and allowed to travel with the flue gases into the steam generator and connective heat-transfer areas.

<u>Targeted Chemical Injection of NOx Reducing Agents</u>

[0051] Targeted chemical injection of NOx reducing agents 20 may also be employed to further reduce NOx emissions. Such a technique, an example of which is disclosed in more detail in U.S. Patent Application No. 10/___,___, filed on September __, 2003, which is commonly owned with the present invention and which is hereby incorporated by reference in its entirety, involves controlling the

combustion process so as to enable one to inject pollutant-reducing reagents or chemicals (such as amine reagents in the case of NOx reduction) into a nearby turbulent combustion zone without a destruction of the chemical by high temperatures. This enables the chemical to be widely dispersed by the nearby zone before reaching the more distal zone where typically more favorable conditions prevail and thus enable the chemical to react with undesirable components of combustion and reduce pollutants such as NOx.

[0052] An example of such a targeted chemical injection system 20 in use is shown in Figure 8. A stream of a chemical, as suggested with dashed lines 32, is introduced into the combustion zone 34 to reduce a combustion pollutant such as NOx. The chemical can be selected from a variety of chemicals. The chemical can be encased within liquid droplets to survive the transit of a hot nearby zone 1 located in front of the burner 36. The burner 36 (being shown as a staged burner) typically has various combustion zones characterized by a turbulent flame zone 1 anchored in front of burner 36 . Zone 1 is highly turbulent and can be characterized as having generally a temperature and stoichiometric profile suitable for NOx reduction with a rapid reagent injection (RRI). A zone 2 is characterized by high temperatures, which tend to be too hot for a lean selective non-catalytic reduction chemistry (SNCR). A distal zone 3, located after the nearby zone 1, also tends to less favorable for the reagent used to reduce NOx in the combustion zone. Distal zone 4, typically has a more suitable temperature and stoichiometric

ratio for SNCR chemistry. However, zone 4 is located quite aft in the combustion zone 34 and preferably is reached with the injection of reagents after these have been widely distributed by the more turbulent but hotter zones 1 and 2. Accordingly, the invention involves reducing the peak temperatures of the zones 1 and 2.

[0053] Once such lower peak temperature condition has been attained the natural turbulence of the combustion process within the zones can be relied upon to thoroughly mix the chemicals with the products of combustion before the chemicals reach the destination zones such as zone 4. The lowering of the peak temperatures in a zone 1 is not sufficient to protect the injected chemicals from deterioration since temperatures are still quite high. Accordingly, it is preferred that injected reagent chemicals are encapsulated within liquid or aqueous droplets that are so sized as to survive transit through the hot regions while evaporating by the time that the chemicals reach the distal zones to be treated by the reagent. Alternatively the reagent chemicals can be encapsulated within a refractory material or a solid material with the encapsulations being ablated within the hot proximal transit zones. Other encapsulation materials can be oils or the reagent can be merely retained in a liquid suspension. In another case the reagent can be introduced within a stream of gas that is selected to protect the reagent during its transit through intermediate hot zones. The protective gas can envelop the reagent and when imparted with sufficient velocity can traverse the hot zone,

though with less mixing by the turbulent intermediate zone. In such case the protective gas can produce a sub-stoichiometric channel through a zone in which the peak temperature exceeds the deterioration temperature of the reagent within the channel without destroying the reagent before it reaches the desired zone.

[0054] Using the system of the present invention, total NOx reduction up to about 90% can be achieved on fossil fuel fired units. The above-described layers of the system can be selectively combined to achieve specific NOx reduction targets for any given boiler. Moreover, the above-described layered approach to NOx reduction results in lower capital and operating costs (including the benefit of not requiring the costs associated with catalyst replacement) as compared to SCR systems. These factors enable the system of the present invention to achieve the lowest cost per ton of NOx removed when compared to known NOx control technologies.

[0055] Furthermore, the first three layers of the above-described system (i.e, burner modifications, overfire air and NOx tempering) may be used in conjunction with an SCR system to achieve lower operating costs (reduced urea or ammonia consumption) and extended catalyst life. However, when all five layers of the above described system are employed, NOx emission reduction on the order of that of SCR can be attained at a greatly reduced cost to implement and operate. More specifically, with the system of the present invention, the initial capital

expenditure can be approximately 40%-70% less than the implementation of an SCR system. Moreover, installation of a system in accordance with the present invention typically requires less down time of the boiler, usually one week, as compared to the six to eight weeks required for alternative approaches, such as SCR.

[0056] The present invention, therefore, provides a system and method for reducing pollution components from a combustion process which is relatively highly effective at reducing NOx emissions, which is relatively simple in design and operation as compared to other known processes which are of comparable effectiveness at reducing NOx emissions, which is relatively inexpensive both to implement and operate as compared to other known processes which are of comparable effectiveness, and which does not rely upon selective catalytic reduction (SCR).

[0057] Although the invention has been described with reference to a particular arrangement of parts, features and the like, these are not intended to exhaust all possible arrangements or features, and indeed many other modifications and variations will be ascertainable to those of skill in the art.